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THE EFFECTS OF HYDROGEN EMBRITTLEMENT OF TITANIUM

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ABSTRACT

Titanium alloys, by virtue of their attractive strength to density ratio, fatigue, fracture toughness and corrosion resistance are now commonly used in various aerospace and marine applications. The cost, once very expensive, has been reduced making titanium even more of a competitive material today. Titanium and titanium alloys have a great affinity to several elements. Hydrogen, even in small amounts, can cause embrittlement, which in turn causes a reduction in strength and ductility. The reduction of strength and ductility is the subject of this investigation.

SUMMARY

Specimens of alpha-beta titanium were tensile tested to determine the effects of hydrogen embrittlement on room temperature mechanical properties, primarily the strain rate dependence of ductility. The combination of stress concentrations and hydrogen contamination decrease the strength of this alloy. A decrease of strength at the lower strain rates was observed.

TABLE OF CONTENTS

LIST OF FIGURES

I. INTRODUCTION AND BACKGROUND

Titanium (Ti), named after the Greek God Titan, was discovered in 1791, but was not commercially produced until the 1950s. Although expensive, the high strength-to-weight ratio of titanium and its corrosion resistance at room and elevated temperatures make it attractive for applications such as airframe structures, jet engines, missile and spacecraft parts, marine components, submarine hulls, and biomaterial such as prosthetic devices. Titanium alloys have been developed for service at 1000° F for long periods of time and up to 1400° F for shorter periods.

Titanium and titanium alloys are classified into three major categories according to the predominant phases present in the microstructure. Titanium has a hexagonal close packed crystal structure called alpha at room temperature. At approximately 1600° F, the alpha phase transforms to a body centered cubic structure called beta, which is stable up to approximately 3000° F (1).

Alloying elements favor either the alpha or the beta phase or are neutral. Alpha-beta titanium alloys are a compromise between the single phase alpha and beta alloys. Alpha phase stabilizing interstitials include aluminum, oxygen, nitrogen and carbon. The beta stabilizing interstitials include copper, chromium, columbium, iron, manganese, molybdenum, tantalum, vanadium and hydrogen (2).

Titanium alloys have a great affinity to the beta stabilizing interstitial hydrogen. Two types of hydrogen embrittlement will be exhibited; these have been designated impact embrittlement and low strain rate embrittlement. The type of hydrogen embrittlement that is most often encountered in high strength alpha-beta titanium alloys is the low strain rate type. Sensitivity of titanium alloys to low strain rate appears to increase with increasing tensile strength, notch severity, alpha grain size, continuity of the beta phase and the hydrogen content (3).

II. TEST PROCEDURES

2.1 MATERIALS AND EQUIPMENT

The testing methods selected for the investigation of hydrogen embrittlement were based on the slow strain rate sensitivity of alpha-beta titanium alloys. Specimens for the test were 3/8 inch diameter round gage alpha-beta titanium rods 7 inches in length. The specimens were machined to reduce the mid-section diameter to 0.250 inches. The ends were threaded to a 3/8-16 pitch thread (Figure 2-1). The large ratio of thread diameter to gage diameter was required to prevent brittle failure in the threads. All tensile tests were made using a Tinius Olsen tensile testing machine using an appropriate load scale.

2.2 TEST RESULTS

Two different strain rates were used. At a strain rate of 0.05 inches per minute from 0 load to failure, the ultimate tensile strength of the specimen was 191,900 psi. At a strain rate of .005 inches per minute from 0 load to failure, the ultimate tensile strength was 173,560 psi. The breaking strength was 161,950 psi and 135,670 psi respectively. The stress-strain curves are shown in Figure 2-2.

2.3 MICROSTRUCTURES AND HARDNESS

The microstructure of the titanium specimen (Figure 2-3) shows fine alpha grains (light) and intergranular beta. Microhardness tests revealed a case hardness of HK 876.4 (HRC 66.0) with a .002 inch depth, then rapidly decreasing to HK 380.2 (HRC 39). Figure 2-4 is the fracture surface of specimen 1 showing a flat break. The higher strain rate yielded a much higher tensile strength than the slow strain rate of specimen 2 (Figures 2-5 and 2-6) where a rough fracture surface with deep internal and surface cracking occurred.

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Figure 2-1. Alpha-beta Titanium Test Specimen

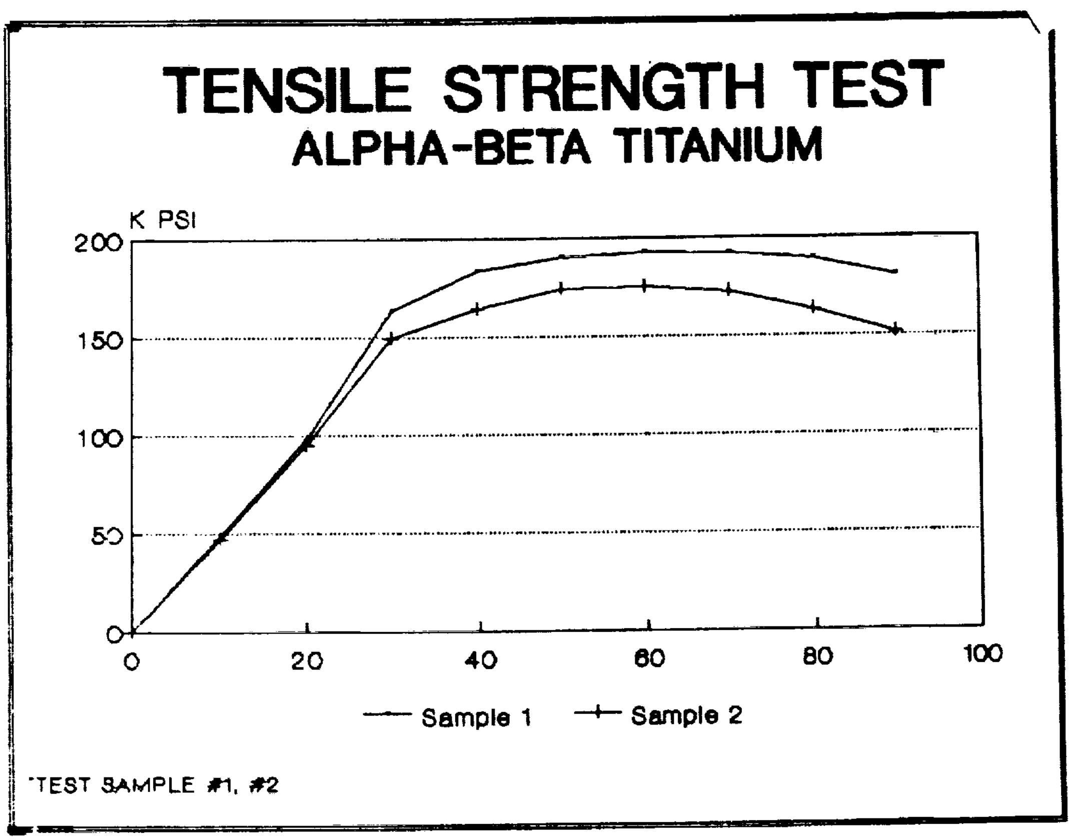

Figure 2-2. Stress Strain Curves of Alpha-beta Titanium Test Specimens

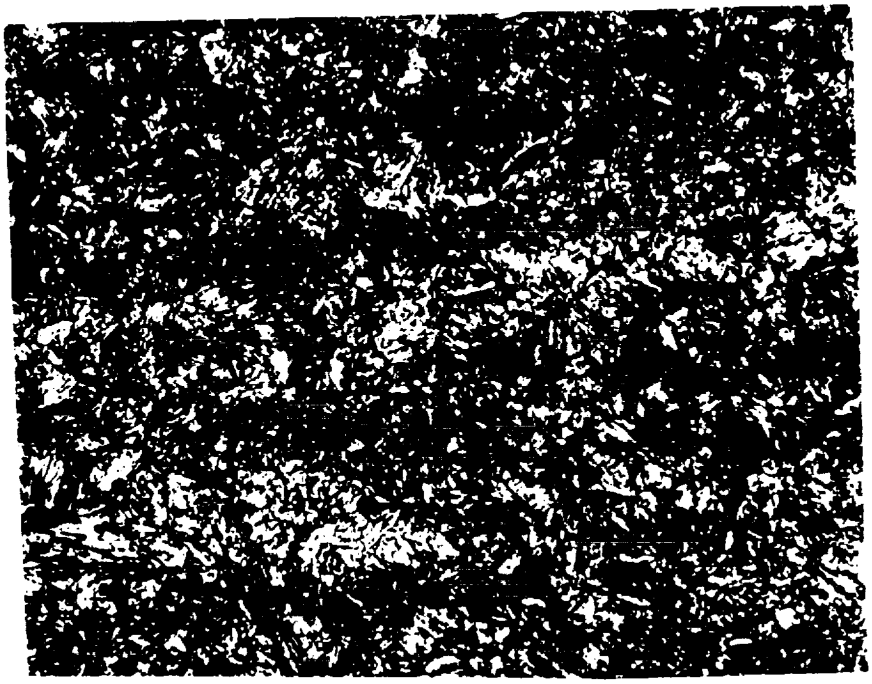

Figure 2-3. Microstructure of Titanium Alloy

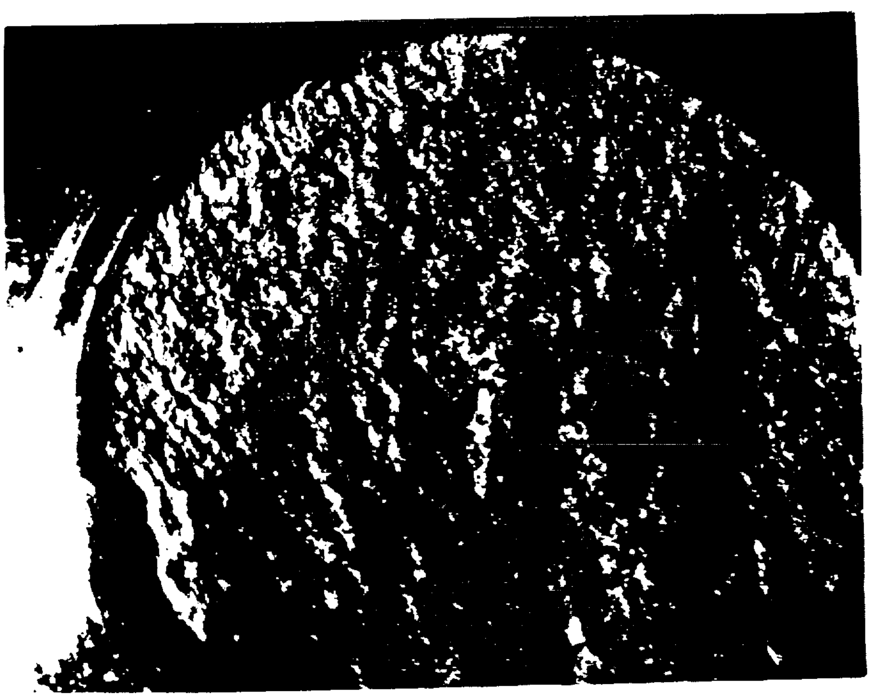

Figure 2-4. Fracture Surface of Specimen Number 1

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Figure 2-5. Fracture Surface of Alpha-beta Titanium Specimen Number 2

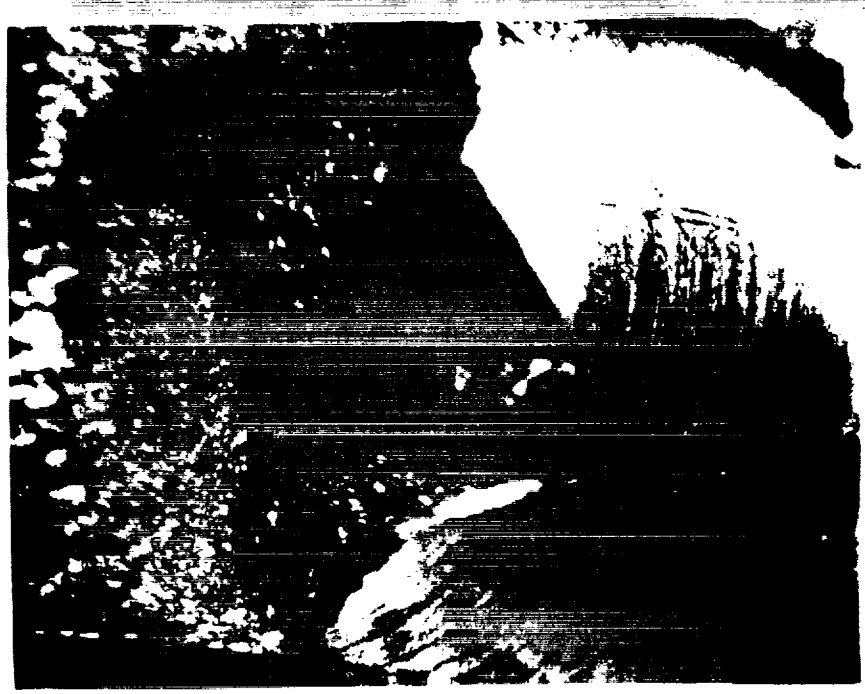

Figure 2-6. Fracture Surface of Alpha-beta Titanium Specimen Number 2

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